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Application of Computational Technologies and Systems in Disease Diagnosis

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Abstract. One of the sectors with the greatest socio-economic impact is the health sector of any country, involving organizations, institutions and professionals that provide health care and welfare services to the population. In modern medicine, there is a complex network of technologies that challenge the conventional limits of clinical practice. Both in research and in the practice of various medical activities, a fundamental part of this field is information systems. In recent years, various computational techniques and tools have been developed and applied with great success in the prevention, diagnosis and treatment of diseases. Thanks to technological development, it is possible to raise the level of services and improve people's quality of life. Within the field of diagnostic, several technologies and computational tools exist that allow medical professionals to make visual assessments of regions where it is difficult to access physically, thus making procedures faster, more efficient and non-invasive. This article gives an overview of the evolution of computational technologies and systems focused on the medical area, which have brought significant advances in the detection and treatment of diseases and provides some examples of application.

Keywords. Computer systems, informatics systems, health technologies, mobile health, digital technologies.

1 Introduction

In the imperious need of human beings to perform their daily activities quickly and efficiently, they have been given the task of imagining, planning, designing and manufacturing tools that allow them to perform such activities. The evolutionary development of man is not only focused on physiological and anatomical changes, but also considers the skills and social behaviors in situations that need to be solved [1]. Since ancient civilizations, man has been developing an impressive capacity to communicate his ideas, which has generated diversity in culture and technological innovation.

According to Turing, digital computers were created with the idea that they could perform any activity that a human being could do [2]. In fact, that a computer would have the ability to mimic the behavior and execute what a human being does, but with the actions in science and technology, where have we arrived and where will we get to?

Evolution in science and technology encompasses a series of events by which a new technology, system or product is discovered or invented and this in turn generates new opportunities for research and the generation of more technology.

2 Fundamentals of Computational Systems in Medicine

In its beginnings, computing was introduced and developed as a multidisciplinary [3] field. Currently, with its implementation in various disciplines and the interrelation between them, it has become a transdisciplinary field, and one of the pillars of science and technology. As time went by, it evolved both in hardware and software, developing computational systems as key elements in the solution to society's needs [4]. A clear example of this is the health sector, where the integration of advanced technologies in computer systems,

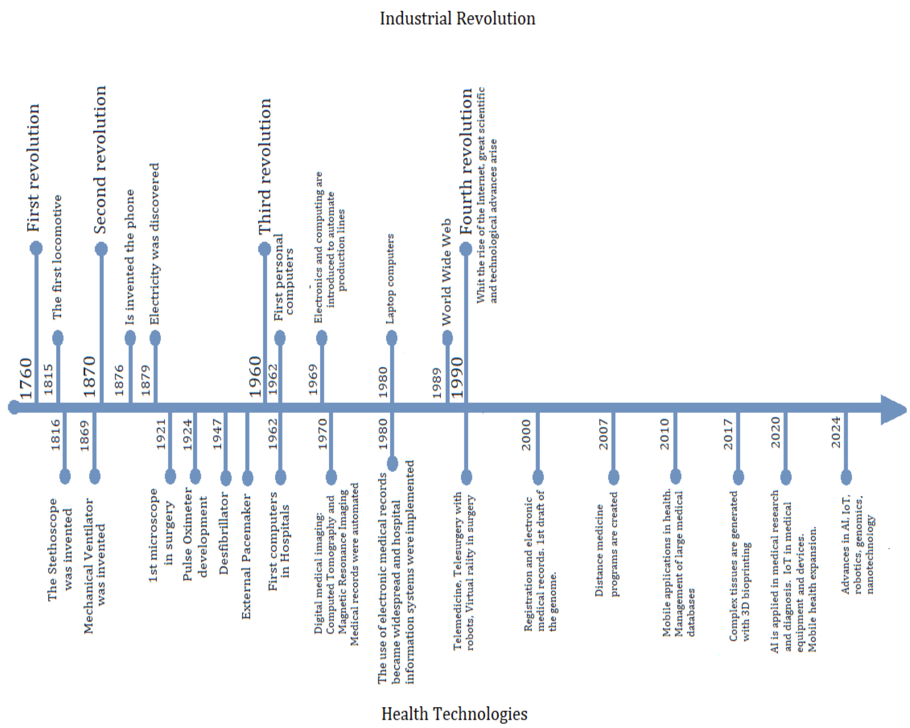

Fig. 1. Timeline of the Industrial revolution in health technologies

technologies related to medical informatics [5] and the use of the Internet [6] have become essential elements.

Today the computer is a fundamental tool in the life of the human being and its potential is evident in the transformation of medicine and health care [7]. The management and analysis of patient data allows healthcare professionals to make more informed decisions, improving the experience of patients and professionals [8]. Major impacts and advances in medicine include telemedicine, also known as telehealth or mobile health.

Thanks to the development of sophisticated systems and mobile devices, [9, 10] this modality of medical care offers both physicians and patients the feasibility of communicating and accessing medical information remotely [11, 5], as well as patient follow-up, preliminary diagnoses and improved overall access to healthcare services. A fundamental resource in medical consultation has always been information and today, with the use of state-of-the-art technologies, it is possible to process large volumes of information [12] in a short time, facilitating the management of medical data and improving the accuracy of diagnoses [13].

2.1 Evolution of Computational Systems in Medicine

The emergence of the industrial revolution in the 18th century not only marked a turning point in science and technology, but also laid the foundation for the reinvention of science and technology as new methods and technologies were developed, which changed the socio-economic state of the world [14, 15].

As a stage in the industrial revolution emerged, improvements in society's living conditions were generated, and with it came the impetus for both research and new technological developments [16]. An example of this is the computer systems whose impact extended to various fields, such as health. In this sense, it is possible to think of a temporal correlation between the stages into which the industrial revolution is divided and the stages in which health technology has developed (Figure 1).

Since ancient times, there have been many advances in medicine with the invention of devices such as the first stethoscope, the microscope, the mechanical ventilator, the first electrocardiogram, the implementation of the first pacemaker, the discovery of X-rays, the introduction of surgical techniques, heart transplants and the obtaining of the DNA double helix, among others [17].

However, the introduction of electronics in industry and the arrival of computational systems prompted a remarkable advance in the development and implementation of hardware and software systems aimed at promoting the welfare of society. From the development of information theory in the 1940s, information is considered as an organized set of data that has meaning and relevance, and that can be processed and describe something.

However, in this decade, medical records were only made with patient questioning, where certain information was provided for a first diagnosis and the records were written on paper. In this way of providing health care, inaccurate or late diagnoses were made, which could lead to the patient being prescribed inappropriate and sometimes unnecessary treatment [18], increasing the health problem or even putting his or her life at risk. Likewise, the requisition of medicines and communication with other areas was done from person to person, by means of the pneumatic tube or by telephone.

In the 1950s, technological developments and applications for medical information management began. The evolution of medical informatics dates back to the 1950s, with the development of the first computer systems and the first medical databases [19]. These developments focused on tasks such as data collection, clinical data storage, data visualization by means of punched cards [20].

By the 1960s, debate began on how computers could improve medical practice by providing rapid access to patient information regarding the results of procedures [21]. The appearance of the first computers in hospitals led to the management of administrative and medical records [22], and the digital storage of patient data.

Also, the use of computers had great repercussions on medical statistics and important discoveries in epidemiology and other disciplines [23]. In this decade, the use of robotics in medical surgeries was proposed, although years later it was put into practice. In the 1970s, the automation of electronic medical records [16] and the development of clinical information systems began [24]. As a result, medical informatics and computer systems were seen as promising technologies for supporting medical decisions and diagnoses. The foundations were also laid for the integration of telemedicine.

Equipment and medical devices were developed, and medical imaging technology emerged, playing a fundamental role in the diagnosis of health disorders through tools and methods for capturing, processing, storing and visualising images. Although this type of technology is applied in various fields, the benefits have been experienced in the medical field, which has given greater impetus to the integration of computers in this field [25].

In the 1980s, with the introduction of the laptop computer, whose cost and size decreased, and the development of operating systems, increased storage capacity and memory, data processing improved healthcare.

Hospital information systems were introduced to manage patient records, and the use of electronic medical records became widespread. (Oyeyemi, Olawumi, Chidi, Okolo, & Babawarun, 2024) and minimally invasive surgery (Pugin, Bucher, & Morel, 2011).

Since the 1990s, the Internet has boomed with interactive information and updates [21], and computers have been used in various sectors that have benefited from major scientific and technological advances. [26, 27]. It was in this decade that the first applications of Virtual Reality (VR) in surgery began.

The first multi-purpose surgical robot (Da Vinci) approved by the US Food and Drug Administration (FDA) was also introduced [28]. The field of robotic surgery has progressed rapidly since then, successfully performing a variety of surgeries and offering stability, precision, greater range of motion and telesurgery thanks to imaging technology with advanced algorithms for image processing and system control [29].

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Over time, new technologies will not only improve the quality of medical care, but also make procedures safer, more efficient and more accurate. In this ever-changing world, computer systems, information technologies and medicine continue to evolve [30].

Recent inventions such as the use of three-dimensional (3D) printing to create more targeted medicines, the rapid production of prostheses or human organ and tissue structures [31], the increasing use of telemedicine or mobile health, and a variety of intelligent health-related systems [32].

These systems include hardware, electronic devices, microprocessors and biosensors. Software includes learning algorithms, connectivity, databases and user interfaces. This allows people to have a personal assistant thanks to advanced computing power and applications in smart devices such as mobile phones, watches or rings.

Smart systems offer a variety of services to help monitor vital signs, physical activity, sleep patterns, and other applications that contribute to the diagnosis and treatment of disease [33]. All of these technological advances in computer systems and informatics technologies are based on research and have changed clinical practice and improved healthcare in general [34].

3 Computational Technologies and Tools in Medical Diagnosis

The advancement of science and technology can be seen as an interrelated and cumulative process in which discoveries and inventions in one area generally drive developments in other areas, such as computer systems in the medical field.

In medical practice, diagnosis is a fundamental step in making decisions and prescribing appropriate treatment. Over time, the introduction of digital technologies and computational tools has revolutionised the way in which various issues in the prevention, diagnosis and treatment of disease are addressed [35]. It has also improved the accessibility and flexibility of healthcare.

Derived from this, a cultural transformation known as digital health began, (known as eHealth with the use of information and communication technologies, now known as mhealth with the use of mobile technology) [36] where disruptive technologies led to changes in medical practice and therefore in the doctor-patient relationship [37].

Digital health is considered a discipline that involves clinicians, scientists and engineers with expertise in diverse areas such as medicine, medical informatics, information technology, biomedical engineering [38], electronic engineering and computer systems, systems control, among others.

This discipline encompasses different uses of digital technologies, internet of things (IoT), artificial intelligence (AI), big data analytics, robotics and machine learning [39], mobile technology and has given rise to concepts such as computational medicine and digital medicine. Although these concepts are interrelated, their approaches and objectives are different.

Computational medicine focuses on the use of computational tools, its main motivation lies in mathematical modelling, the development of processing methods, normalisation and data integration and analysis, machine learning and deep learning methods, computational simulation techniques focused on biomedical problems [40], neural networks are also used in the solution of large problems, fuzzy logic for decision making and diagnosis of diseases and evolutionary algorithms for the optimisation of results [41, 42].

Another big step in research is the integration of nanotechnology for diagnosis and treatment of diseases, regenerative and gene therapy, as well as the aesthetic industry [12].

Digital medicine takes an approach that integrates digital hardware and software technologies to promote health through prevention and care management, i.e., it focuses on the interaction between the patient and the healthcare professional using digital technologies.

Even with all this progress, digital technology is still heavily operator-dependent [43] and there are unresolved issues such as security, reliability and ethics, among others. However, every day new ideas, developments and innovations emerge that will provide answers to these challenges.

4 Technology and Computational Tools

4.1 Artificial Intelligence

In the 1950s, artificial intelligence (AI) was proposed as a predictive machine, where hardware or software could present behaviour that appeared intelligent by predicting associations between variables. In the 1970s, the progress of AI was halted because it did not solve complex problems. In this period the boom was in the development of expert systems based on inference and knowledge base engines, deep learning and neural networks. With these developments, experts in different disciplines used AI adapted to real problems [44]. Thus, AI has contributed to the medical field by offering efficiency and speed in the diagnosis of diseases.

4.2 Virtual and Augmented Reality

It is a technology that emerged in the 1960s, where the first portable virtual reality screen was created and placed on the head to transmit digital sensory information with control of what the user sees [45]. This technology allows the user to immerse themselves in a three-dimensional environment. In the 1980s, the term VR was used for the first time and in the 1990s the first application in medicine began.

In recent years, the use of VR has increased and the concept of augmented reality was born, which uses VR elements and superimposes them on the real environment. New VR and AR systems are in constant development, offering portable devices such as joysticks, keyboards, glasses, and nowadays using integrated body tracking technologies, which allow to explore highly immersive, interactive and dynamic environments, or non-immersive and static ones [46].

4.3 Computer- Assisted Learning

Digitalisation in this time has boosted the use of various computer programmes to facilitate learning. This type of learning has been applied to subjects such as neuroscience, surgery, radiology, pharmacology, among others [47]. The simulation technique aims to recreate a visual clinical scenario that represents a situation or object under study using computer tools to acquire knowledge, develop skills, practice and evaluate learning. Multimedia technology allows the creation of programmes that can be adapted to the user's needs for further learning in a particular area [48].

4.4 Telemedicine and the Internet of Things

Telemedicine or telehealth (mobile health) is the modality of remote medical care that uses information and communication technologies such as computer systems and the internet of things. Currently, the miniaturisation of electronic devices is a trend that is impacting industries worldwide, which has enabled the development of advanced systems in reduced formats, i.e. compact devices that allow user monitoring and transmission of user information via the internet to the medical team [34]. In addition to the diversity of mobile applications focused on health care through diets, exercise, vital signs monitoring, breathing control, stress management, measurement of blood glucose levels, blood pressure measurement, among others.

4.5 Big Data and Data Mining

In order to analyse and obtain big data, it is necessary to use analytical techniques to make predictions and generate trends based on previous data. In the medical area, these techniques make it possible to process large volumes of patient data, identify patterns and relationships between them, and develop predictive models through data mining [49].

4.6 Medical Robotics- Robotic Surgery

Computer systems have given a great impetus to robotics, which is found in many applications in the automotive industry for the automatic execution of repetitive operations. Robotic surgery arose from the need to improve the surgeon's skills in minimally invasive procedures (master-slave systems) [50]. From the concept of telepresence [28] and robotic telemanipulation system, the development of telesurgery arose.

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Table 1. Summary of the technologies and computational tools used to provide better health services

TECHNOLOGY	COMPUTATIONAL TOOLS
Artificial Intelligence (AI)	– Machine Learning – Supervised and unsupervised learning - Decision trees - Support Vector Machines - Artificial Neural Networks - Unsupervised learning - Clustering algorithm – Deep Supervised Learning - Perceptron - Convolutional Neural Networks - Recurrent Neural Networks – Supervised Deep Learning - Boltzmann Machine - Autoencoder - Generative Adversarial Network
Virtual and Augmented or Mixed Reality	– Machine and deep learning – 3D VR models – Mobile and web-based applications
Computer-assisted learning Multimedia	– Machine Learning – Artificial Neural Networks – Expert systems and inference rules – Computer software
Telemedicine Internet of Things	– Computing tools and service platforms – Web-based and mobile applications
Big Data Data mining Block Chain	– Deep learning – Classification algorithms – Regression – Clustering – Reinforcement – Neural networks – Consensus algorithm
Medical robotics and Rehabilitation robotics	– Control algorithms – Vision and classification – Machine learning
Medical electronic equipment	– Classification algorithms – Neural networks – Machine learning – Web tolos
3D printing	– Images and vision processing and segmentation algorithms – Machine learning algorithms – Automatic control algorithms

Table 2. Summary of some applications of computational technologies and tools

APPLICATIONS	REF.
– Diagnostic imaging (imaging volume)	[58]
– Genomic medicine	[59]
– Diagnosis of neurological disorders	[60]
	[61]
– Pathology analysis (damaged cells-classification)	[62]
– EEG and ECG analysis	[63]
– Analysis of cardiac conditions (classification)	[64]
– Computer-aided diagnosis	[65]
– Neurosurgery by superimposing digital information on the surgical field	[66]
– Surgery simulation	
– Use of mobile virtual reality for medical understanding	
– Rehabilitation	[67]
– Self-directed learning in health (diagnosis and prediction of diseases)	[48]
– Information Access	[47]
– Development of computational thinking	
– E-learning in medical education	
– Presenting information using various media at the same time	
– Exercise, rehabilitation, Psychotherapy, Neuro-rehabilitation	
– Hospital networks	
– Cybersecurity in connected medical devices (IoMT) such as remote-controlled	[68]
insulin pumps	[69]
– Cybersecurity in pacemakers	[70]
– Medical information	
– Statistics and analysis of large amounts of data	[49]
– Neurological diagnostics	
– Computer assisted surgery	[50]
– Robotic surgery	[71]
– Hybrid operating theatres	
– Prosthetics and exoskeletons	[71]
– Neuroprosthetics in rehabilitation and brain injuries	[52]
– Control based on myoelectric pattern recognition	[72]
– Equipment cyber-risk prediction and analysis	[53]
– Pacemakers, defibrillators, infusion pumps, dialysis machines.	[74]
– Prosthetics, printing of cells or organs for medical research, education and	[55]
training, printing of drugs in specific doses and with multiple layers of sustained	[56]
and immediate reléase	[57]

4.7 Rehabilitation Robotics-prosthetics, Exoskeletons

The application of advanced technologies to rehabilitation robotics led to the development of assistive and therapy robots. This type of rehabilitation is focused on recovering or improving the functionality and mobility of people with physical disabilities or injuries. Robotic rehabilitation is an alternative that relies on wearable robots to supplement the function of a limb or replace it. Robot control is based on pattern recognition of surface myoelectric signals [51, 52] and detection of the movement intention of these signals.

4.8 Medical Electronic Devices and Equipment

There is a wide range of networked medical electronic devices and equipment on the market and as science and technology continue to advance, these devices continue to evolve with new versions, brands and types. Networked medical equipment, or the internet of things, consists of computer systems that enable the measurement of medical parameters with the ability to store, manipulate, visualise and transmit the information, as they can be connected to electronic platforms.

This facilitates remote medical care, remote patient monitoring and real-time information management. Today, one concern is cyber-attacks on transmitted information and unauthorised access to information. However, experts are working to adopt security policies to limit access to sensitive information, [53, 54].

4.9 3D Printing

Rapid prototyping or 3D printing is a technology also called additive manufacturing, whereby layers of a given material are deposited one on top of the other to create the three-dimensional solid object of interest. This technology has many applications in the medical field, such as the creation of medicines, anatomical models and prostheses. [31, 55, 56, 57]. Selected technologies and computational tools can be summarized as shown in table 1, some of their applications in table 2.

5 Conclusions

The development of computer systems and information systems has impacted every aspect of contemporary society. Digital technologies have transformed the way we interact with the world, giving rise to a cultural revolution that promotes a change in mentality and ideology. Current advances in science and technology will continue to drive the development of new knowledge and more advanced technology.

Today, one can speak of the positive impact of technology in various fields, particularly in the field of health. Existing technology allows for more effective diagnosis and treatment of diseases, patient care and access to health information remotely, providing a better quality of life for those suffering from a disease and for the people around them.

As well as increasingly smaller smart devices and various mobile applications, which make this experience a personal assistant. The ability to handle huge volumes of information and more powerful learning and control algorithms in computer systems and robots, with artificial intelligence technologies and the internet of things, have made life easier.

However, all this technological innovation does not always happen, nor does it reach all countries in the same way, perhaps due to a lack of funding and support for technology development and research projects. However, technology will continue to evolve and there will always be questions and challenges to be solved.

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